GRIP-LIP Contributions to the Ongoing Study of the Sources and Currents in the Global Electric Circuit

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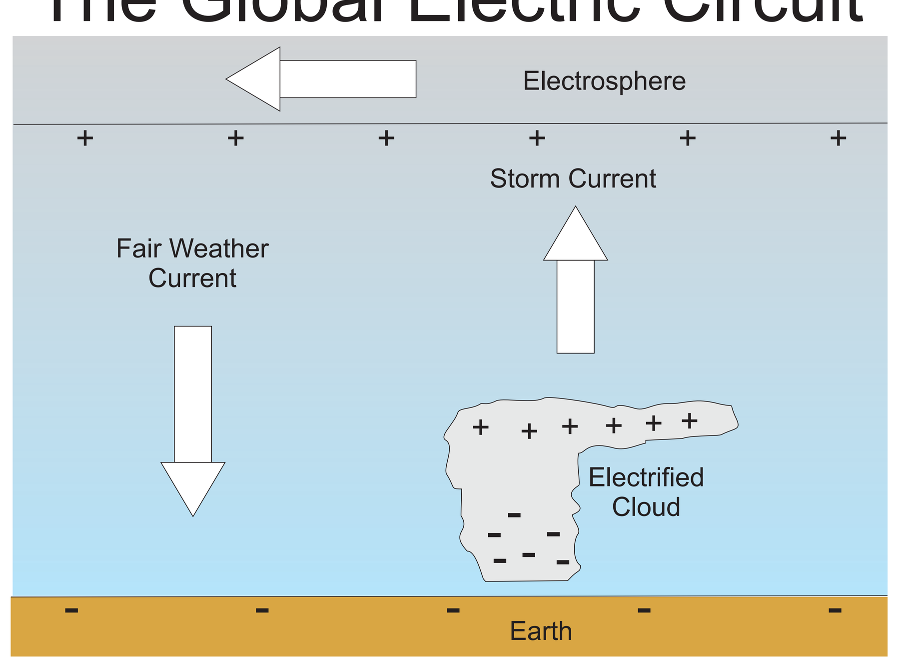
Genesis and Rapid Intensification Processes (GRIP)
Science Team Meeting
Wallops Flight Facility, VA
May 2012

Diurnal variations of the fair weather electric field as a function of UTC were characterized by measurements from the Carnegie and Maud research ships. The source of these variations in the global electric circuit was theorized to be from the diurnal variations in thunderstorms and other electrified clouds. Much subsequent research on the global electric circuit has focused on linking the fair weather field variation – commonly called the Carnegie curve – to worldwide variations in electrified weather by using the proxy of lightning rates. For example, some found worldwide thunderday statistics produced a curve with similar phase, but incorrect amplitude variation to the Carnegie curve. Others obtained results with orbital lightning climatology data from the Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS) similar to the earlier thunderday statistics in that they agree with the Carnegie curve in phase, but not in amplitude.

One important objective of our high altitude aircraft observations of electrified clouds, which were initiated in the late 1980's, was to measure the electric current output of these storms as a function of electric field and lightning. We have recently shown that a combination of the airborne data and the orbital based lightning climatology can correct the lightning-based estimates of the global electric circuit diurnal variation. We have already published ground breaking results using our 850 aircraft storm overflight data sets prior to GRIP. We found that land storms had greater lightning rates than ocean storms but smaller mean conduction (Wilson) currents. We also found that electrified, non-lightning-producing storms – henceforth, referred to as electrified shower clouds (ESCs) make a measurable contribution to the global electric circuit, particularly for ocean storms.

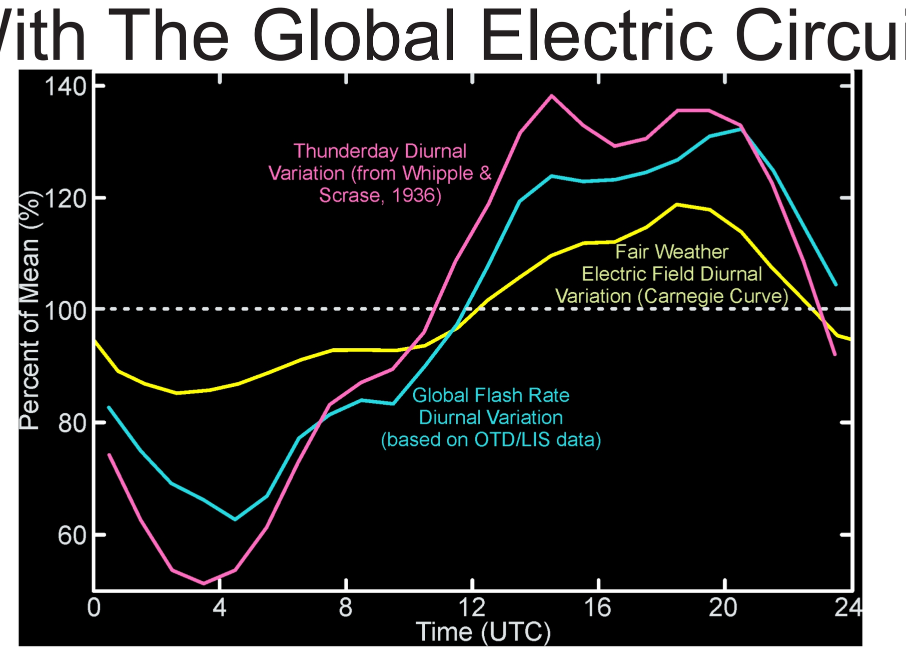
Although there were only 5 sorties with the Global Hawk aircraft in GRIP, the nominally 24 hour missions provided many more opportunities for storm overflights. The GRIP flights contributed an additional 213 storm overflights to our database, raising the total to 1063 (a 25% increase over the non-GRIP data). Although the GRIP data have not radically changed the relevant statistics (land/ocean/lightning/nonlightning), the extra data refined the statistics, supported our earlier assumptions, and allowed us to expand the analysis to seasonal data. A recently submitted manuscript on the seasonal variation in the global electric circuit indicates how data from a program such as GRIP (using an aircraft with a very long flight duration) can make a significant difference in the data analysis.

The Global Electric Circuit

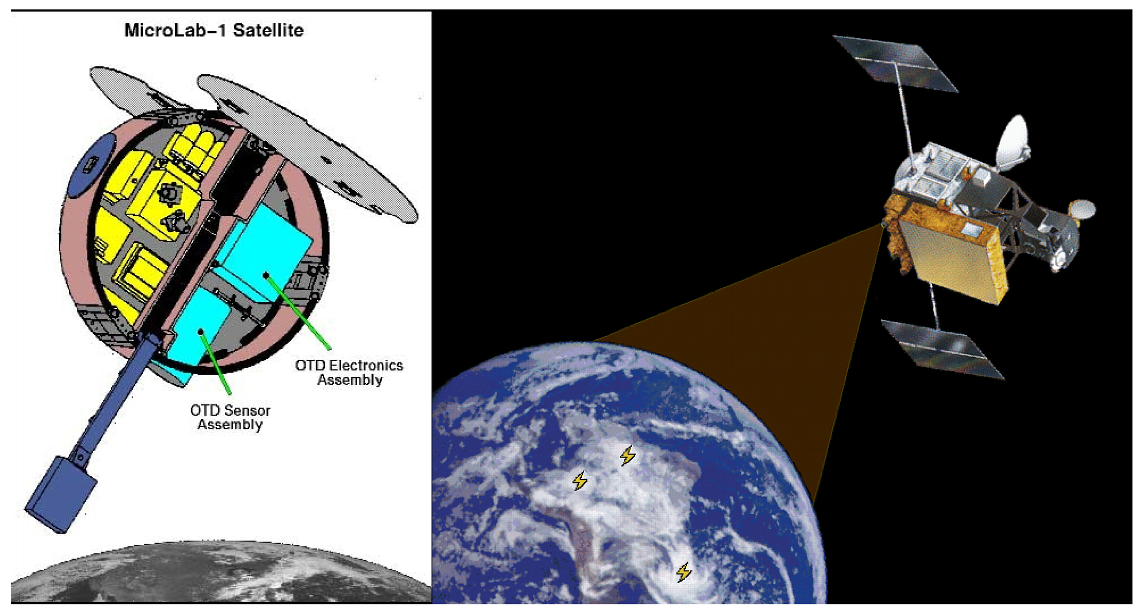


- We are using two of our unique datasets, including storm overflight data to answer some of the questions about the Global Electric Circuit
  - Are thunderstorms the source of the current in the Global Electric Circuit?
  - How important are land/ocean or lightning/non-storm differences?
- The fair weather electric field diurnal variation matches the phase of the thunderstorm activity
  - Why the different amplitudes?
  - Are there non-thunderstorm sources missing?

Diurnal Variations Associated With The Global Electric Circuit

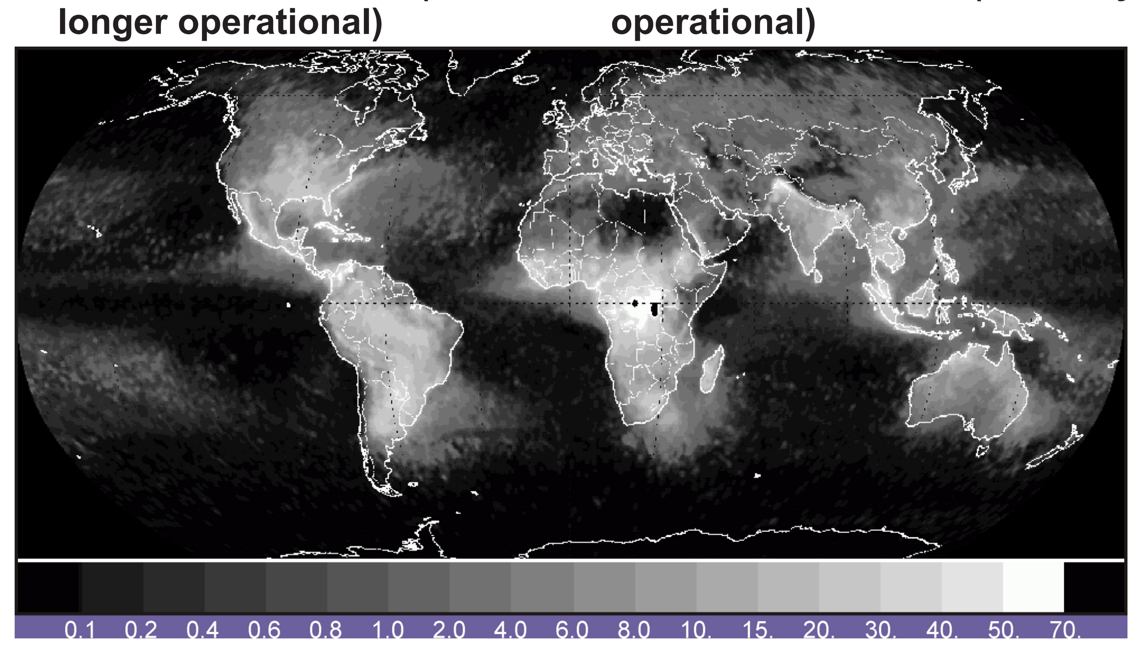


Satellite Based Dataset



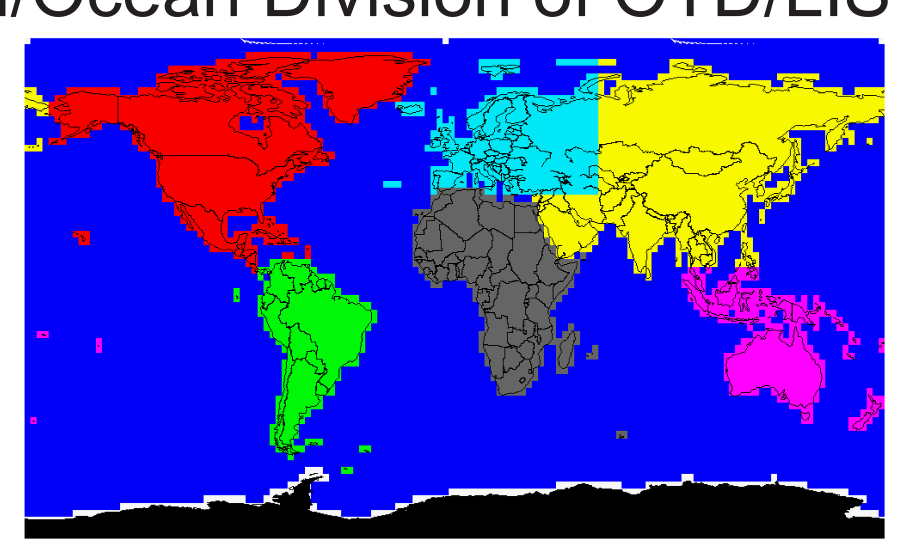
Optical Transient Detector (OTD)
- Microlab-II
- ~10 km pixel
- ~1300x1300 km FOV
- 710 km altitude
- Data from 1995-2000 (no longer operational)

Lightning Imaging Sensor (LIS)
- Tropical Rainfall Measuring Mission (TRMM)
- ~6 km pixel
- ~600x600 km FOV
- 350-400 km altitude
- Data from 1998-2010 (currently operational)

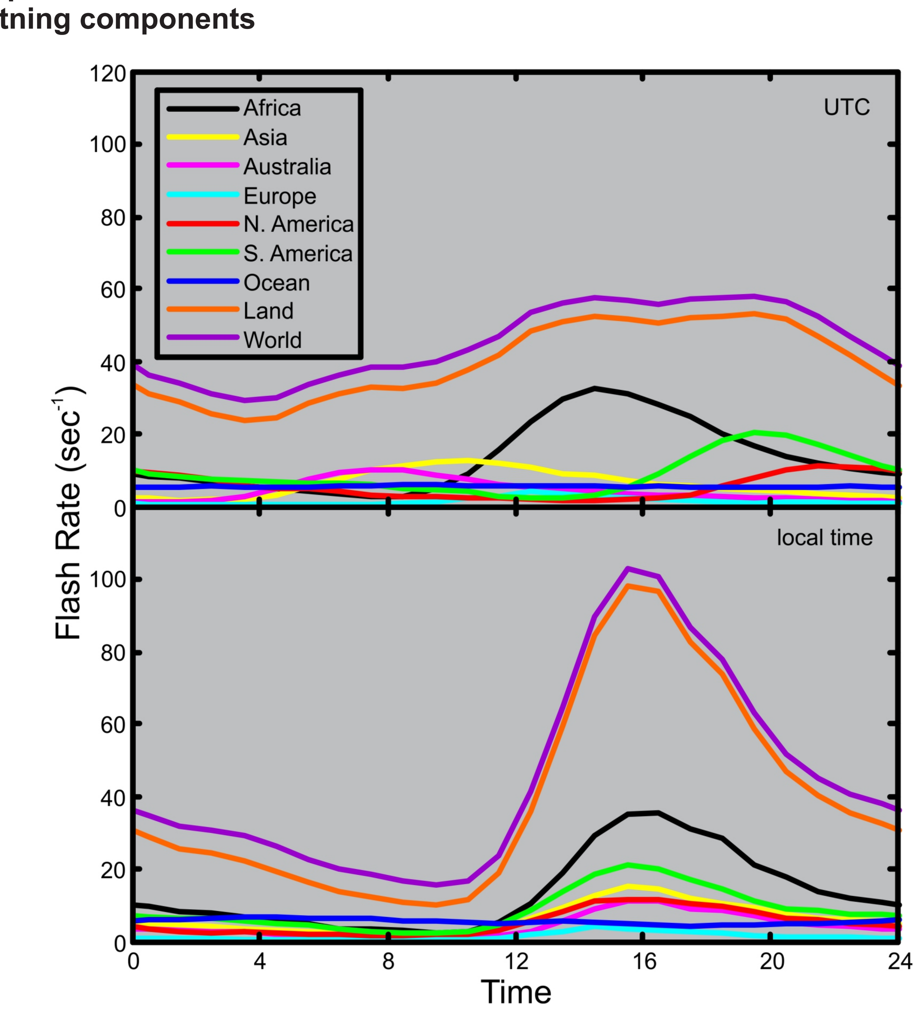


Plot of the combined OTD/LIS data showing the global distribution of lightning

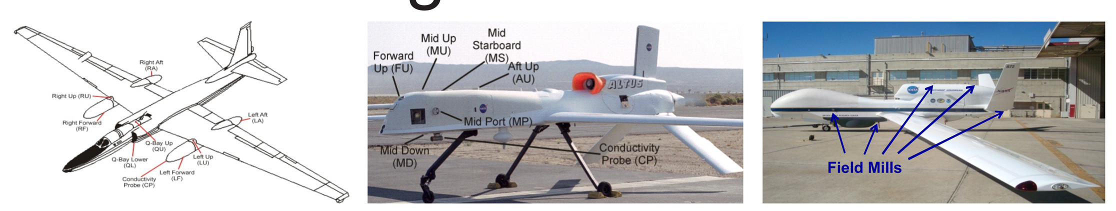
Land/Ocean Division of OTD/LIS Data



- The orbital based lightning data was divided into land and ocean components
- The top plot shows the various continental and ocean lightning divisions
- The plot below shows the diurnal variation in the various continental and ocean lightning components



Overflight Data Aircraft

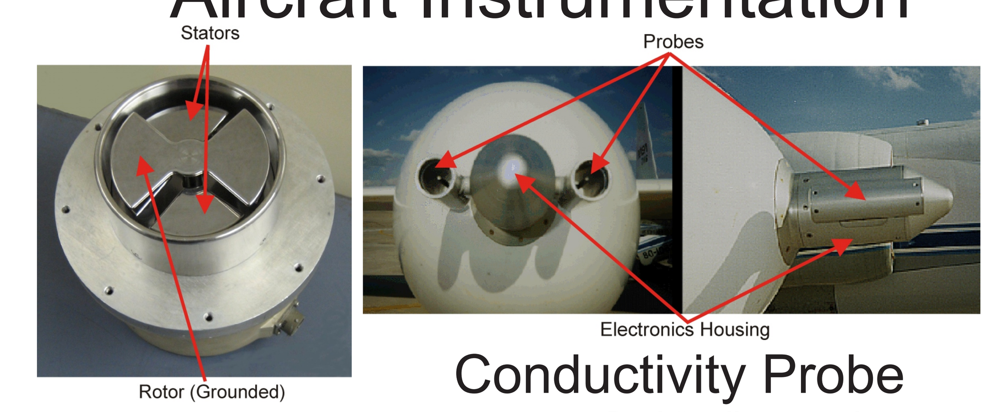


ER-2
- 20 km nominal altitude
- 210 m s^{-1} nominal speed
- 8 FM locations
- Piloted

Altus II
- 15 km nominal altitude
- 35 m s^{-1} nominal speed
- 6 FM locations
- UAV

Global Hawk
- 18.5 km nominal altitude
- 170 m s^{-1} nominal speed
- 6 FM locations
- UAV

Aircraft Instrumentation



Field Mill

- Laboratory sensitivity +/- 1.9 V m^{-1} to 1.1 MV m^{-1}
- Aircraft sensitivity (via calibration matrix) +/- 1 V m^{-1} to 500 kV m^{-1}
- 50 Hz sample rate
- 10 Hz frequency response

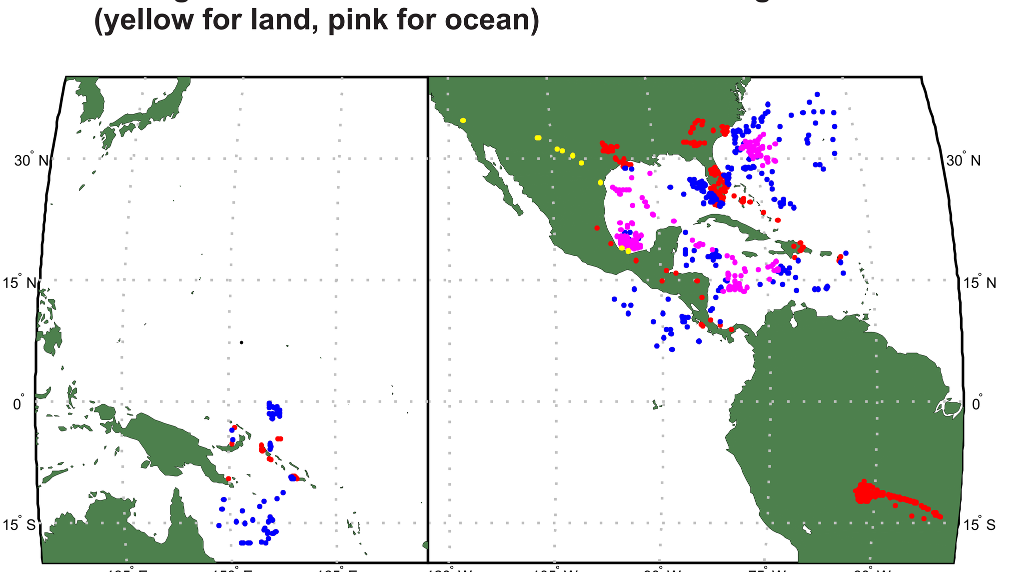
Conductivity Probe

- Dual Gerdien capacitor conductivity probe
- At aircraft flight altitudes, able to determine conductivity values from 0.02 pS m^{-1} to 14 pS m^{-1}
- Calibration error (systematic error) of about 7%
- Measured noise floor (random error) of about 0.005 pS m^{-1}

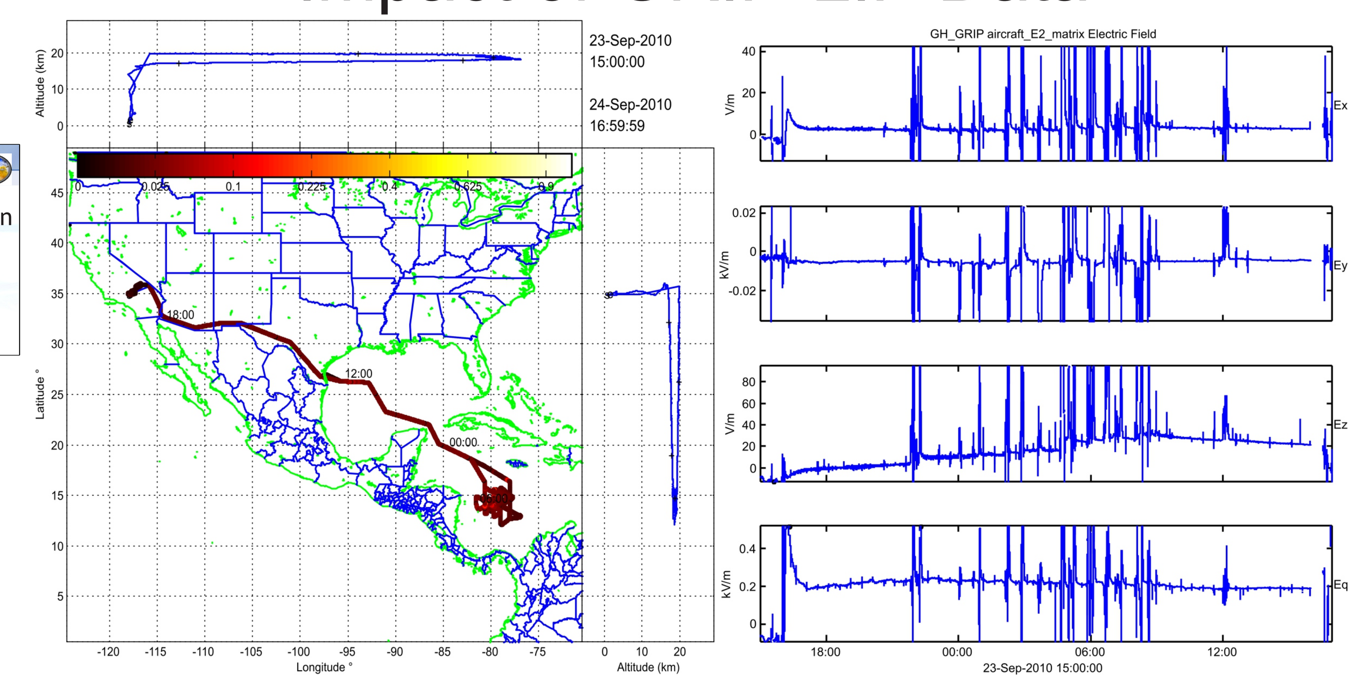
Overflight Dataset Statistics

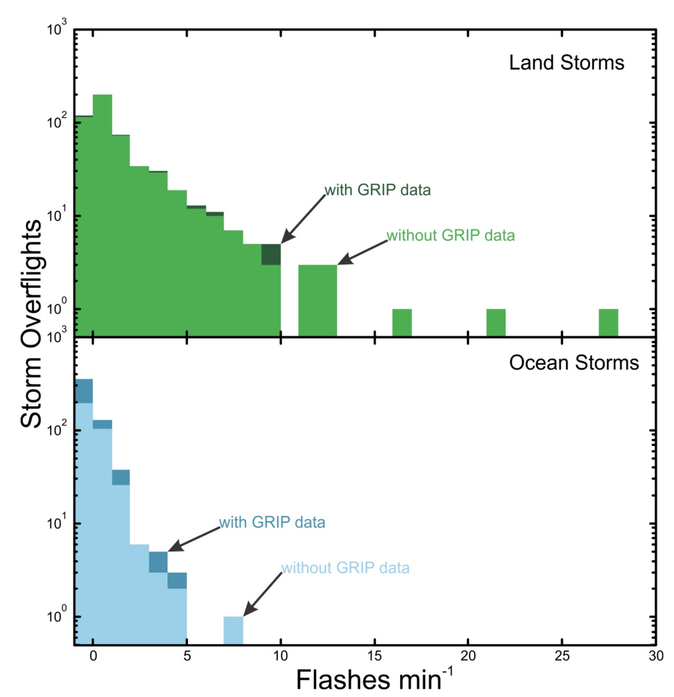
Campaign (month, year)	With Lightning	Without Lightning	Land	Oceanic	Total Overflights
TOGA-COARE (Jan-Mar, 1993)	14	64	19	59	78
CAMEX-1 (Sep-Oct, 1993)	13	25	15	23	38
CAMEX-2 (Aug- Sep, 1995)	29	7	11	25	36
TEFLUN-A (Apr-May, 1998)	39	8	43	4	47
TEFLUN-B (Aug-Sep, 1998)	35	3	35	3	38
CAMEX-3 (Aug-Sep, 1998)	37	38	19	56	75
TRMM-LBA (Jan-Feb, 1999)	192	63	255	0	255
CAMEX-4 (Aug-Sep, 2001)	52	35	22	65	87
ACES (Aug, 2002)	76	22	80	18	98
TCSP (Jul, 2005)	54	44	15	83	98
GRIP (Aug-Sep, 2010)	48	165	11	202	213
Totals	589	474	525	538	1063

- Although there were only 5 sorties in GRIP with electrified clouds, the long duration missions resulted in over 200 overflights of electrified storms
- These overflights increased our database by almost 25%, from 850 to 1063
- The table above shows how the 213 overflights contributed to the various overflight categories (land/ocean/lightning /non-lightning)
- The figure below shows where the GRIP overflights occurred (yellow for land, pink for ocean)



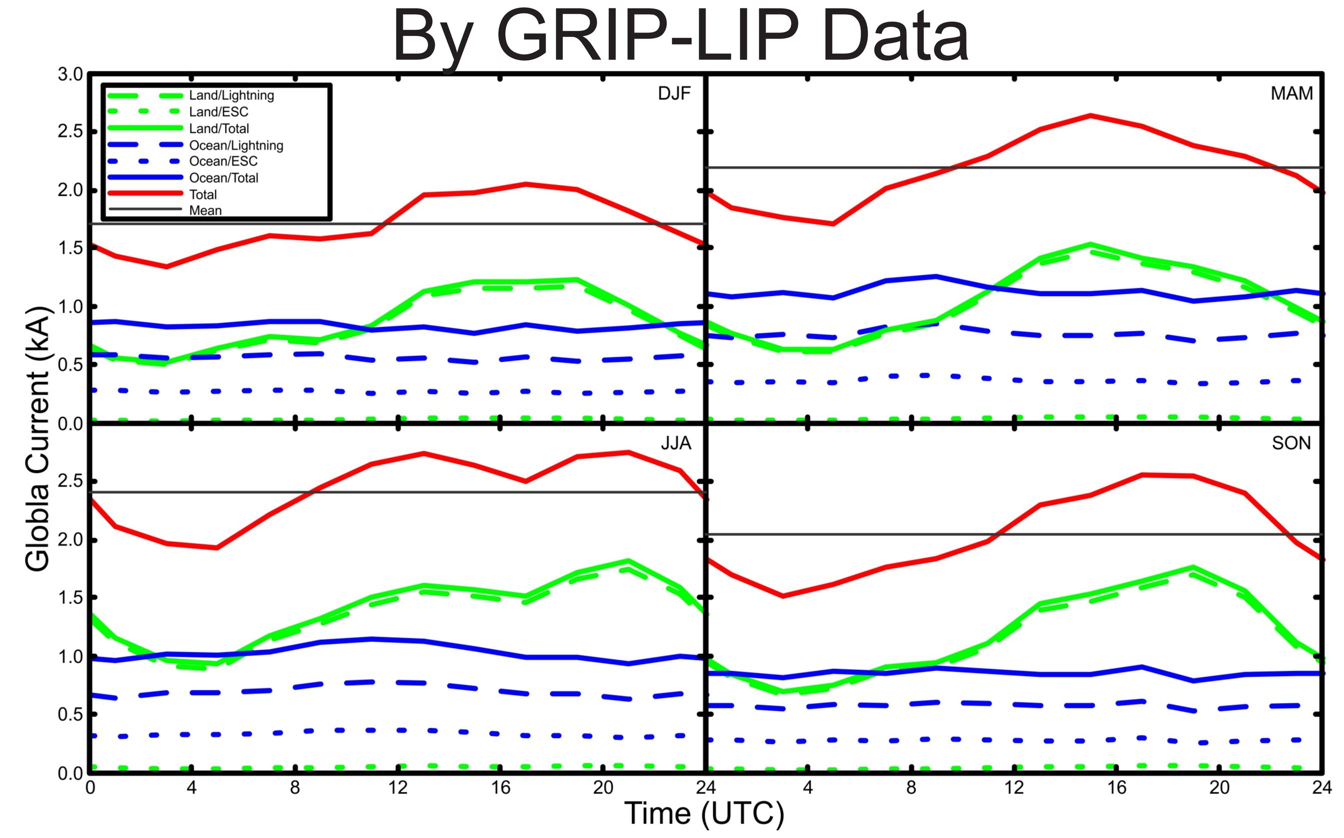
Impact of GRIP-LIP Data



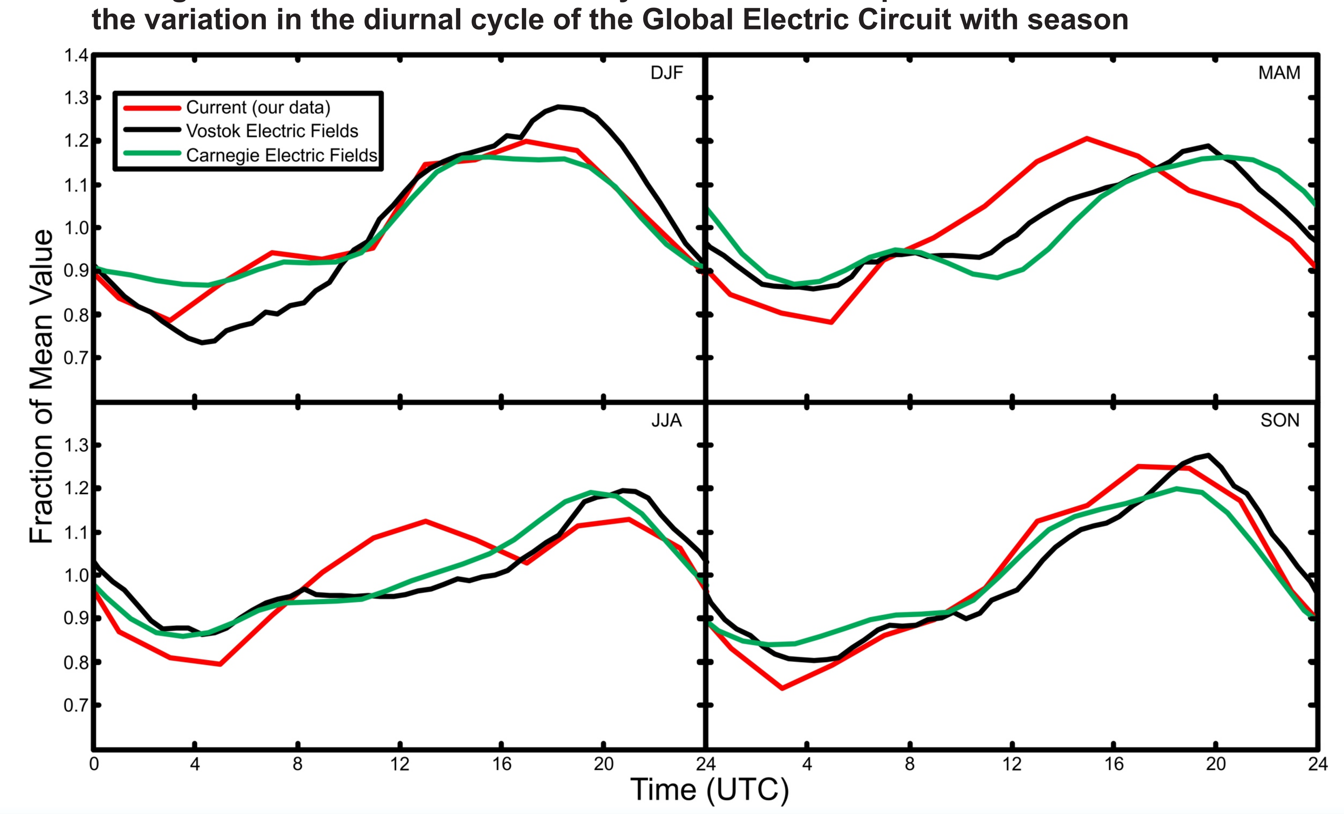


- **Added storms to all categories**
  - Land storms (11)
  - Ocean storms (202)
  - Lightning storms (48)
  - Non-lightning storms (165)
- **Pattern of GRIP-LIP data confirmed assumptions made in prior analyses**
  - Land storms usually have lightning
  - Ocean storms have much less lightning
  - Ocean storms have higher mean DC fields (and therefore higher currents)
  - Ratio of lightning to non-lightning storms stayed about the same
  - Mean flash rates for ocean/land storms were also nearly constant
- **GRIP-LIP data was evolutionary, not revolutionary**

Expansion of Analysis Aided By GRIP-LIP Data



- Along with more orbital lightning data, the extra overflights with GRIP-LIP allowed us to expand our analysis of the Global Electric Circuit to include seasonal variations
- We found that the seasonal variation in the Global Electric Circuit, based on our analysis, matches other established measures of the Global Electric Circuit seasonal diurnal variation, further enhancing the utility of our analysis
- The top plot is our estimates of the seasonal variations in the diurnal cycle of the Global Electric Circuit
- The figure below shows how our analysis matches with prior established measures of the variation in the diurnal cycle of the Global Electric Circuit with season



Conclusions. The impact of the electrification data from GRIP-LIP to our study illustrates how datasets collected with long flight duration aircraft, such as the Global Hawk, can make a significant contribution to the advancement of the science of atmospheric electricity. With these aircraft, much more time can be spent in the vicinity of the storms of interest. The long duration of the missions also mean that targets further way from the launch point can be studied for significant periods of time. Although our LIP system was not designed for 24+ hour missions, we were able to adapt our data collection and data analysis software and hardware to accommodate the larger volume of useful data.